

Micrometer Gravitinos and the Cosmological Constant

Christof Schmidhuber*

CERN, Theory Division, 1211 Genève 23

Abstract

We compute the 4-dimensional cosmological constant in string compactifications in which the Standard Model fields live on a non-supersymmetric brane inside a supersymmetric bulk. The cosmological constant receives contributions only from the vacuum energy of the bulk supergravity fields, but not from the vacuum energy of the brane fields. The latter is absorbed in a warp factor. Supersymmetry breaking on the brane at the TeV scale implies supersymmetry breaking in the bulk at the micrometer scale. This creates a tiny cosmological constant that agrees with experiment within a few orders of magnitude. Our argument predicts superpartners of the graviton with mass of order $10^{-3}eV$. They could be observed in short-distance tests of Einstein Gravity.

*christof.schmidhuber@cern.ch

1. Introduction

The observed smallness of the cosmological constant λ in Einstein's equations poses a fine-tuning problem already in classical field theory coupled to gravity. E.g., when the Higgs field rolls down its potential, the energy density of the vacuum and thus the effective value of λ changes by a large amount. Other expected contributions to λ that are suspiciously absent include those from condensates in QCD.

But perhaps the most mysterious aspect of the problem is that λ does not seem to receive contributions from the quantum mechanical ground state energies

$$\rho_k = \frac{\hbar\omega}{2} \quad , \quad \omega^2 = k^2 + m^2$$

of the oscillators with momentum k of the massless and light fields of the Standard Model. Summing these contributions up to some large-momentum cutoff $\Lambda \gg m$, one finds in the case of a single-component bosonic field [1]:

$$\lambda = 8\pi G \int_0^\Lambda \frac{k^2 dk}{2\pi^2} \rho_k \sim \frac{\Lambda^4}{2\pi} l_P^2 . \quad (1.1)$$

Here, G is the Newton constant and $l_P = \sqrt{\hbar G} \sim 1.7 \cdot 10^{-35} m$ is the Planck length (setting $c = 1$). Experimentally, it presently seems that [2]

$$\lambda \sim (2 \cdot 10^{-33} eV)^2 \sim (10^{26} m)^{-2} \quad (1.2)$$

(setting $\hbar = G = 1$). $10^{26} m$ is the order of magnitude of the curvature radius of the universe, which is roughly the inverse Hubble constant. But even if one considered only the contributions of the two helicity states of the massless photon to the cosmological constant (1.1), then in order to explain such a small value of λ one would need a momentum-cutoff as small as

$$\Lambda \sim \frac{1}{100} eV \sim \frac{1}{20 \mu m} .$$

So the minimum wavelength would have to be as large as $20 \mu m$. Already the wavelength of visible light is much smaller than $20 \mu m$. In this sense the observed smallness of the Hubble expansion parameter seems inconsistent even with what we can see with our bare eyes.

Supersymmetry could explain a zero cosmological constant, because the vacuum energies of the superpartners cancel each other. Supersymmetry looks so much like the missing piece

in the puzzle that it has been questioned whether supersymmetry is really broken [3]. But if it isn't broken, it is of course hard to explain why we do not see superpartners of the Standard Model fields [4].

The recently revived suggestion that we live on a 4-dimensional brane that is embedded in a higher-dimensional bulk opens up a new perspective and a way out (under an assumption stated in section 2). It will be proposed below that supersymmetry is indeed unbroken up to micrometer scales – but only in the *bulk* supergravity theory. By a simple argument, supersymmetry breaking in the bulk at micrometer scale is derived from supersymmetry breaking at the TeV scale on the brane, which carries the Standard Model fields.

Due to a mechanism first proposed in [5] and re-invented in [6, 7], the vacuum energy of the brane fields is shown not to contribute to the $4d$ cosmological constant. Rather, it is absorbed in the curvature transverse to the brane. Only the vacuum energy of the bulk supergravity fields is argued to contribute to the $4d$ cosmological constant.

This vacuum energy is estimated. The result is a relation between the Planck mass m_{Planck} , the scale $m_{Brane-Susy}$ of supersymmetry breaking on the brane, the scale $m_{Bulk-Susy}$ of supersymmetry breaking in the bulk sector and the Hubble expansion rate H_0 : roughly,

$$\log \frac{m_{Planck}}{m_{Brane-Susy}} \sim \frac{1}{2} \cdot \log \frac{m_{Planck}}{m_{Bulk-Susy}} \sim \frac{1}{4} \cdot \log\left(\frac{m_{Planck}}{H_0}\right) \quad (1.3)$$

(a more detailed relation is given in the text). Based on the known values of m_{Planck} and H_0 , this relation predicts gravitinos or other superpartners of the supergravity multiplet with masses of order $10^{-3}eV$ (which is inside experimental bounds [8]) and a supersymmetry breaking scale on the brane of $2 - 6 TeV$. Conversely, based on the assumption that supersymmetry is restored in the Standard Model at energies not too much above the weak scale, the relation explains the observed small value of the cosmological constant.

The setup is introduced in section 2. In section 3 it is argued that the $4d$ cosmological constant is zero as long as the bulk supergravity theory is treated classically. In section 4 it is shown that the quantum mechanical ground state energy of the supergravity sector produces a cosmological constant that is within a few orders of magnitude of its observed value. Precise matching yields the predictions for supersymmetry breaking in the Standard Model and in the bulk sector, as explained in section 5. Section 6 contains conclusions.

2. The setup

We consider a 3-brane soliton that is embedded in a $(4 + n)$ -dimensional bulk spacetime (figure 1). We assume that the n extra dimensions are compactified on some manifold \mathcal{M} . The Standard Model fields are assumed to live only on the brane, while gravity lives in the bulk. Let $\text{Vol}(\mathcal{M})$ be the volume of the compactification manifold, and let $\text{Vol}(\mathcal{B})$ be the volume of the ball \mathcal{B} inside \mathcal{M} that intersects with the brane. Since we are going to consider non-supersymmetric branes inside supersymmetric bulks (as, e.g., in [9]), we will identify the size (i.e. the thickness) of the brane with $l_{\text{Brane-Susy}} \sim m_{\text{Brane-Susy}}^{-1}$, the scale of supersymmetry breaking in the Standard Model. So roughly, $\text{Vol}(\mathcal{B}) \sim (l_{\text{Brane-Susy}})^n$.

Similarly as in [10], because the Einstein action is integrated over $\text{Vol}(\mathcal{M})$ while the Standard Model action is integrated only over $\text{Vol}(\mathcal{B})$, the 4-dimensional Planck length l_{Planck} is related to $l_{\text{Brane-Susy}}$ by

$$\left(\frac{l_{\text{Planck}}}{l_{\text{Brane-Susy}}}\right)^2 = \left(\frac{m_{\text{Brane-Susy}}}{m_{\text{Planck}}}\right)^2 \sim \frac{\text{Vol}(\mathcal{B})}{\text{Vol}(\mathcal{M})} \quad (2.1)$$

(assuming a $(4 + n)$ -dimensional Newton constant of order one).

Let us first consider the supersymmetric version of the story. So we assume that we have a supersymmetric brane inside a supersymmetric compactification manifold. In string theory, this is achieved by considering a compactification on a Calabi-Yau 3-manifold that involves branes parallel to the 4-dimensional space-time, as in [11]. At distances much larger than the size of the compactification manifold, only a four-dimensional supersymmetric effective theory of Standard Model fields plus their superpartners coupled to 4d supergravity is seen.

For concreteness, we may assume a metric in the vicinity of the brane of the form

$$ds^2 = dr^2 + f(r) \hat{g}_{\mu\nu} dx^\mu dx^\nu + g(r) d\Omega_5^2$$

where r denotes the distance from the brane, x^μ are the space-time coordinates parallel to the brane, $\hat{g}_{\mu\nu}$ is the 4d metric parallel to the brane, and $f(r), g(r)$ are some functions. Supersymmetry of the effective 4d theory implies that the 4d metric $\hat{g}_{\mu\nu}$ is Ricci-flat (we are assuming that there are no 4-form gauge field strengths or expectation values of other supergravity fields), i.e. the effective 4d cosmological constant is zero.

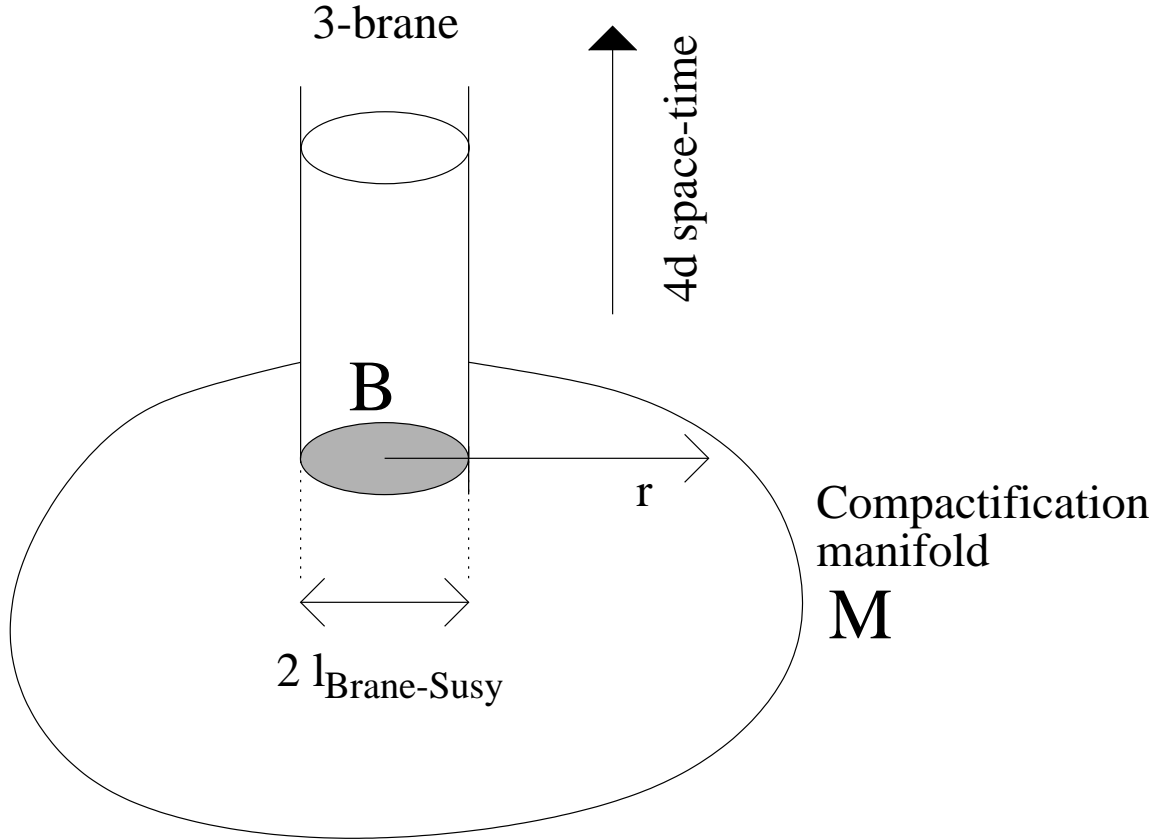


Figure 1: A 3-brane in a $(4 + n)$ -dimensional embedding space.

Now suppose that we cut out a region of radius $l_{Brane-Susy}$ around the brane. The basic assumption under which the arguments in the next section apply is that, at the level of *classical* supergravity, we can consistently do the following: we can replace the supersymmetric brane soliton solution by a stable non-supersymmetric one (perhaps of the type of [12]), such that the bulk fields smoothly connect to a solution at $r \geq l_{Brane-Susy}$ that does not break supersymmetry on the $4d$ slices parallel to the brane.

In other words, we assume that there are consistent string compactifications that involve space-time filling stable non-BPS branes, such that 4-dimensional supersymmetry is unbroken away from the brane at least in the classical supergravity approximation. The construction of explicit examples must be left for future work.

In the case of one extra dimension, examples of supergravity solutions that smoothly interpolate between a supersymmetric and a non-supersymmetric region are the kink solutions of $5d$ gauged supergravity discussed in [13, 14].

Supersymmetry is now broken not only in the bulk theory in the vicinity of the brane. It is also broken in the world-brane theory that contains the Standard Model fields and lives in the non-supersymmetric gravitational background. This will result in a brane vacuum energy of the order of $(m_{Brane-Susy})^4$.

3. Classical Supergravity Approximation

Let us first explain why the vacuum energy on the brane does not curve the $4d$ metric $\hat{g}_{\mu\nu}$ parallel to the brane (i.e., why it does not create a $4d$ cosmological constant) as long as the bulk supergravity theory is treated classically (see [5, 6, 7]). Although the bulk theory is treated classically, the world-brane theory containing the Standard Model fields is assumed to be treated fully quantum mechanically. Corrections from loops of the bulk fields are very interesting and will be discussed in the next section.

The bulk has been separated into two regions: the non-supersymmetric neighborhood of the brane $M^4 \times \mathcal{B}$, where M^4 is the Minkowski space parallel to the brane; and the supersymmetric region, i.e. the rest of the bulk $M^4 \times (\mathcal{M} - \mathcal{B})$. The classical supergravity equations of motion can be solved separately for each region, and can then be matched at their interface at $r = l_{Brane-Susy}$.

In the bulk region, the $4d$ metric $\hat{g}_{\mu\nu}$ parallel to the brane must still be Ricci-flat because of supersymmetry on the $4d$ slices parallel to the brane.

As for the brane region, there may be a singularity or horizon near the center. Let us therefore restrict the discussion to the region $\epsilon \leq r \leq l_{Brane-Susy}$, where ϵ is a cutoff that hides the singularity or horizon. The issue of boundary conditions at $r = \epsilon$ will be commented on below.

In this non-supersymmetric brane region, the brane is a source of vacuum energy ρ of order $(m_{Brane-Susy})^4$ that arises from the world-brane fields. Let us assume some distribution $\rho(r)$ around $r = 0$ with width of the order $l_{Brane-Susy}$. $\rho(r)$ enters the Einstein equations

like an r -dependent cosmological constant:

$$R_{mn} - \frac{1}{2}g_{mn}R = -\hat{\lambda}(r) g_{mn}$$

with

$$\hat{\lambda}(r) = 8\pi G\rho(r) - \lambda_{flux}(r) .$$

Here we have included another r -dependent contribution $\lambda_{flux}(r)$ that arises when the brane is a source of electric or magnetic flux.

For simplicity, we focus on the example of a single extra dimension, assume a constant dilaton and neglect the other supergravity fields; the generalization is straightforward. We make the metric ansatz

$$ds^2 = dr^2 + e^{2\alpha(r)} \hat{g}_{\mu\nu} dx^\mu dx^\nu .$$

In this ansatz, the $4d$ metric \hat{g} is taken to be r -independent. The 5-dimensional Ricci tensor can be written (cmp. with [7]):

$$R_{\mu\nu}^{(5)} = \hat{R}_{\mu\nu}^{(4)} - \hat{g}_{\mu\nu} e^{2\alpha(r)} (\ddot{\alpha} + 4\dot{\alpha}^2)$$

(a “dot” means $\frac{d}{dr}$). Plugging this into the Einstein equation for the 4-dimensional components (μ, ν) and using the equation for the (r, r) component to eliminate $\ddot{\alpha}$,

$$4(\ddot{\alpha} + \dot{\alpha}^2) = -\frac{2}{3}\hat{\lambda},$$

we obtain:

$$\hat{R}_{\mu\nu}^{(4)} = k^2 \hat{g}_{\mu\nu} \quad \text{where} \quad k^2 = e^{2\alpha} \left(\frac{1}{2}\hat{\lambda} + 3\dot{\alpha}^2 \right)$$

is an integration constant that is by definition the $4d$ cosmological constant ($k^2, \hat{\lambda}$ may be negative). So the equations for α have a one-parameter family of solutions, labelled by the constant $4d$ curvature k^2 . However, matching at $r = l_{Brane-Susy}$ to the solution in the supersymmetric region requires that we pick the solution that is Ricci-flat in $4d$, i.e. $k = 0$. For this solution, the vacuum energy on the brane is completely absorbed by the warp factor

$$\dot{\alpha}^2 = -\frac{1}{6}\hat{\lambda}(r) ,$$

and therefore does not curve the $4d$ metric parallel to the brane. So the vacuum energy does not lead to a $4d$ cosmological constant. For n extra dimensions, the discussion is similar.

This is the mechanism of Rubakov and Shaposhnikov [5], recently rediscovered in [6, 7]. We have supplemented it by a matching condition at $r = l_{Brane-Susy}$ that picks out the solution with vanishing $4d$ cosmological constant without fine-tuning. This is a generalization of the suggestion in [15] of “supersymmetry on the Planck brane” in the context of the Randall-Sundrum model. Higher-order corrections will make the differential equations for α more complicated, and there may be regions in parameter space where no solutions exist [16]; let us assume that conditions are favorable and solutions exist.

We have not discussed boundary conditions for α at the cutoff $r = \epsilon$, where the supergravity approximation presumably breaks down. However, whatever boundary conditions must be imposed – the assumption that they can be satisfied is part of the assumption that we have already made in the previous section: that there are consistent string compactifications that involve stable non-BPS branes and leave 4-dimensional supersymmetry unbroken away from the brane at the classical level. Again, it remains to construct explicit examples.

4. Supergravity at One Loop

Let us now go beyond the classical supergravity approximation. This is the main new step taken in this paper and it will lead to our numerical results.

As mentioned in the introduction, the ground state energies

$$\frac{\hbar\omega}{2} \quad \text{with} \quad \omega^2 = k^2 + m^2$$

of modes of light fields with momentum k should give a quantum mechanical contribution to the cosmological constant. We have already demonstrated that the ground state energy of the Standard Model fields does not contribute to the $4d$ cosmological constant, so it only remains to compute the vacuum energy produced by the bulk supergravity fields: the gravitino, the dilaton, antisymmetric tensor fields etc.

As long as supersymmetry is unbroken in the bulk, these vacuum energy contributions cancel. Now, breaking supersymmetry in the region of the bulk near the brane also breaks supersymmetry in the effective $4d$ theory, obtained by integrating over the compactification manifold \mathcal{M} . But because of the small overlap of the wave functions of the supergravity fields

with the brane, the mass scale $m_{Bulk-Susy}$ of supersymmetry breaking in the bulk sector of the $4d$ effective theory will be suppressed with respect to the scale of supersymmetry breaking on the brane by the same volume factor that we already found in (2.1),

$$\left(\frac{m_{Bulk-Susy}}{m_{Brane-Susy}}\right)^2 \sim \frac{\text{Vol}(\mathcal{B})}{\text{Vol}(\mathcal{M})} \sim \left(\frac{m_{Brane-Susy}}{m_{Planck}}\right)^2. \quad (4.1)$$

One way of seeing this is to consider a scalar field Φ in the supergravity multiplet and assume that it has a large mass of order $m_{Brane-Susy}$ inside the region where supersymmetry is broken: we take its $(4+n)$ -dimensional Lagrangean to be of the form

$$\partial_m \Phi \partial^m \Phi + \theta(r_{Brane-Susy} - r) m_{Brane-Susy}^2 \Phi^2.$$

θ is the step function: $\theta(x) = 0$ for $x < 0$ and $\theta(x) = 1$ for $x \geq 0$. Integrating this Lagrangean over the compactification manifold, the kinetic term acquires a prefactor $\text{Vol}(\mathcal{M})$ while the mass term only acquires a prefactor $\text{Vol}(\mathcal{B})$. After normalizing Φ to have a standard kinetic term, its mass is

$$m_\Phi^2 \sim m_{Brane-Susy}^2 \frac{\text{Vol}(\mathcal{B})}{\text{Vol}(\mathcal{M})}.$$

This implies relation (4.1).¹

So the hierarchy between the scales of supersymmetry breaking in the bulk supergravity sector and supersymmetry breaking in the Standard Model that lives on the brane is the same as the hierarchy between the scale of supersymmetry breaking on the brane and the Planck scale.

Already in the introduction we have discussed the relation (1.1) between the momentum cutoff Λ in the sum over vacuum energies and the value of the cosmological constant λ . In the case of N massless bosonic propagating degrees of freedom, the relation changes to

$$\lambda \sim N \frac{\Lambda^4}{2\pi} l_P^2. \quad (4.2)$$

λ is related to the Hubble expansion rate H_0 of the universe by

$$\lambda = 3\Omega_\Lambda H_0^2 \quad \text{with} \quad \Omega_\Lambda \sim \frac{2}{3}$$

¹The relation $m_\Phi \sim \frac{m_{Brane-Susy}}{m_{Planck}}$ could also have been derived without reference to branes; in this case the suppression factor is simply due to the smallness of Newton's constant.

being the value suggested by observation [2]. In a first estimate we may identify the cutoff Λ in (4.2) with the scale $m_{Bulk-Susy}$ of supersymmetry breaking in the bulk.² Then equation (4.2) implies (converting $l_{Planck} \sim m_{Planck}^{-1}$):

$$\left(\frac{m_{Bulk-Susy}}{m_{Planck}}\right)^2 \sim \frac{6\Omega_\Lambda\pi}{N}\left(\frac{H_0}{m_{Bulk-Susy}}\right)^2. \quad (4.3)$$

A more precise calculation involves the various masses of order $m_{Bulk-Susy}$ of the supergravity fields. Then k in (1.1) is integrated not only up to $m_{Bulk-Susy}$, but up to $k_{max} \sim m_{Brane-Susy}$, which is the fundamental scale in our setup. Formula (1.1) generalizes to (see e.g. [17] for a discussion):

$$\lambda \sim \frac{l_P^2}{2\pi} \times \sum_i (-1)^{F_i} \left\{ k_{max}^4 - \frac{1}{2} m_i^4 \ln \frac{k_{max}}{m_i} + \dots \right\}, \quad (4.4)$$

where i counts the propagating degrees of freedom in the supergravity multiplet, m_i are their masses of order $m_{Bulk-Susy}$ after supersymmetry breaking, and $(-1)^{F_i}$ is $+1$ for bosonic and -1 for fermionic degrees of freedom. The k_{max}^4 terms cancel since there is an equal number of bosons and fermions.³ The conclusion is then that N in (4.3) is replaced by

$$N = Q \sum_i (-1)^{F_i} \left(\frac{m_i}{m_{Bulk-Susy}}\right)^4 \quad (4.5)$$

with

$$Q \equiv -\frac{1}{2} \ln \frac{m_{Brane-Susy}}{m_{Bulk-Susy}}.$$

Together, with (4.1), (4.3) yields the relation claimed in the introduction (where we have set $\Omega_\Lambda = \frac{2}{3}$ and roughly approximated $(\frac{|N|}{4\pi})^{\frac{1}{2}}$ by 1):

$$\log\left(\frac{m_{Planck}}{m_{Brane-Susy}}\right) = \frac{1}{2} \log\left(\frac{m_{Planck}}{m_{Bulk-Susy}}\right) = \frac{1}{4} \log\left(\sqrt{\frac{|N|}{6\Omega_\Lambda\pi}} \frac{m_{Planck}}{H_0}\right) \equiv L. \quad (4.6)$$

²The previous version of this paper used this first estimate (i.e. it set $|Q| \sim 1$ below) to suggest supersymmetry breaking scales of $4 - 10 \text{ TeV}$ on the brane and $10^{-3} - 10^{-2} \text{ eV}$ in the bulk (compare with section 5).

³A possible term of the form $k_{max}^2 \sum_i (-1)^{F_i} m_i^2$ that may appear in a more general calculation should also vanish, since supersymmetry is broken *spontaneously* by the non-supersymmetric soliton inside the supersymmetric bulk.

5. The Numbers

Let us now plug in the numbers. We use

$$m_{Planck} \sim 10^{19} \text{ GeV} \quad (5.1)$$

$$\sqrt{\lambda} = \sqrt{3\Omega_\Lambda H_0} \sim 2 \cdot 10^{-33} \text{ eV} \quad (5.2)$$

What is N ? Type IIB supergravity multiplets, e.g., have 128 bosonic and 128 fermionic degrees of freedom. Without going into details, it seems safe to assume that $|\frac{N}{Q}|$ in (4.5) is somewhere between 1 and 128. With $|Q| \sim 20$, this gives

$$\sqrt{\frac{|N|}{2\pi}} \sim 2 \text{ to } 20$$

Since there may be other hidden factors of $\pi, \frac{1}{2}$, etc. that were missed by our crude analysis, the actual errors in the relation (4.6) may even be somewhat (but not much) larger. Being optimistic about them, we infer that

$$L \sim 15.4 \pm 0.2$$

This yields the predictions

$$m_{Brane-Susy} \sim 2 \text{ TeV} - 6 \text{ TeV} \quad (5.3)$$

$$m_{Bulk-Susy} \sim \frac{1}{2} \cdot 10^{-3} \text{ eV} - \frac{1}{2} \cdot 10^{-2} \text{ eV} . \quad (5.4)$$

The example with the intermediate value of $L = 15.4$ is plotted in figure 2.

So we expect a mass of order 10^{-3} eV for the gravitino or at least for some members of the supergravity multiplet. This corresponds to a Compton wavelegth of the order of a fraction of a millimeter. Similarly as in the case of millimeter-size extra dimensions [10], the presence in the bulk of gravitinos or dilatons in the micrometer range is not ruled out by experiment: while the brane physics (the Standard Model) has been probed down to the weak scale, the bulk physics (gravity) has only been probed down to centimeter scales. The lower experimental bound on the gravitino mass appears to be only 10^{-5} eV [8]. The effects of these new fields might show up in short-distance measurements of gravity in the μm range in the near future [18].

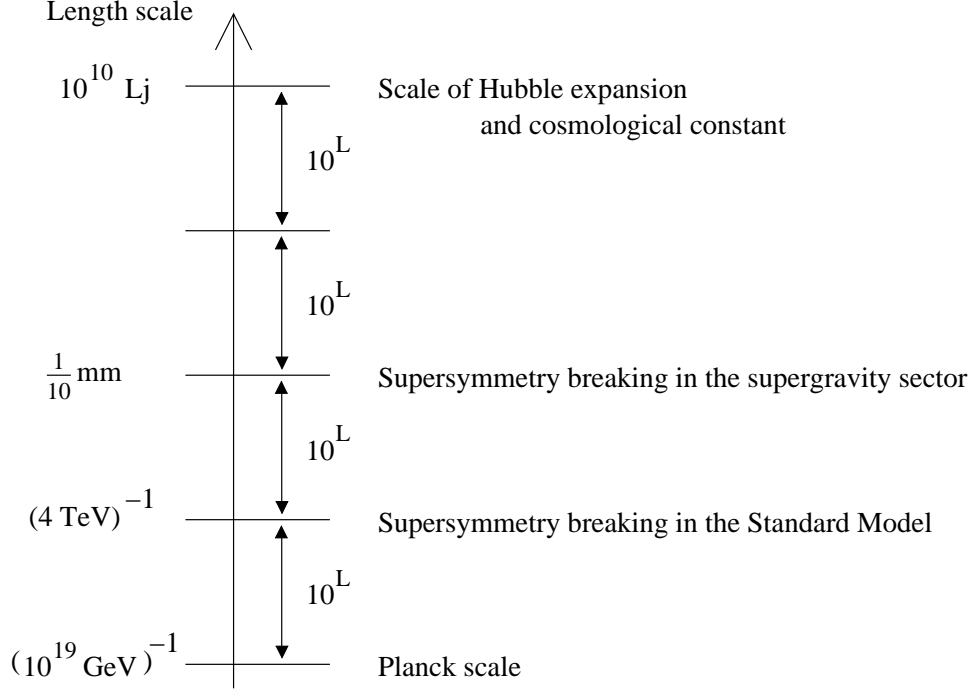


Figure 2: The relation between hierarchies for the intermediate value $L = 15.4$.

Remarkably, the predicted scale of supersymmetry breaking in the Standard Model is roughly where it is expected to be, in order to insure that the running coupling constants meet in supersymmetric Grand Unification. This is very nontrivial; a priori it could have come out many orders of magnitude off the mark. Reversing the logic, if we assume a probable scale of supersymmetry breaking between 1 and 100 TeV, then we can predict the value of the cosmological constant within a few orders of magnitude of the value that seems to have been measured!

Let us finally note that our derivation and results apply just as well to the case of a single extra dimension as in the Horava–Witten model [19] or in the Randall–Sundrum model [20].

Conclusion

It seems that the proposal that we live on a non-supersymmetric brane that is embedded in a supersymmetric higher-dimensional string compactification can explain the observed

small value of the cosmological constant, provided that the scale of supersymmetry breaking in the Standard Model is roughly 2–6 TeV. It remains to construct explicit examples of such compactifications and to show that they are consistent.

Our explanation for the small cosmological constant can be tested by searching for signs of a gravitino, a dilaton or other supergravity fields with masses of order 10^{-3} eV. We can thus look forward to a number of surprises in future tests of Einstein gravity in the micrometer range.

Acknowledgements:

I thank W. Lerche and P. Mayr for discussions. I also thank I. Antoniadis, R. Barbieri, S. Dimopoulos, S. Kachru, G. Veneziano, H. Verlinde and E. Witten for comments on the previous version of this paper. This work is supported in part by a Heisenberg fellowship of the DFG.

Note: After this paper appeared, I was notified by the authors of [21] that they mention on page 5 the possibility of using infinite volume extra dimensions to suppress the breaking of $5d$ bulk supersymmetry and the $5d$ bulk cosmological constant. (Note however that we discuss $4d$ supersymmetry and the $4d$ cosmological constant on slices parallel to the brane.) I also became aware of [22], where non-supersymmetric branes inside a supersymmetric bulk are constructed.

References

- [1] S. Weinberg, The Cosmological Constant Problem, *Rev. Mod. Phys.* **61** (1989), 1.
- [2] N. Bahcall, J. P. Ostriker, S. Perlmutter and P. J. Steinhardt, “The Cosmic Triangle: Revealing the State of the Universe,” *Science* **284**, 1481.
- [3] E. Witten, “Is supersymmetry really broken?,” *Int. J. Mod. Phys.* **A10**, 1247 (1995)
- [4] E. Witten, “The cosmological constant from the viewpoint of string theory,” hep-ph/0002297.

- [5] V.A. Rubakov, M.E. Shaposhnikov, Extra Space-Time Dimensions: Towards a Solution of the Cosmological Constant Problem, Phys.Lett. B125: 139, 1983.
- [6] E. and H. Verlinde, RG Flow, Gravity and the Cosmological Constant, e-Print Archive: hep-th/9912018.
- [7] C. Schmidhuber, “AdS(5) and the 4d cosmological constant,” hep-th/9912156.
- [8] A. Brignole, F. Feruglio, M. L. Mangano and F. Zwirner, “Signals of a superlight gravitino at hadron colliders when the other superparticles are heavy,” Nucl. Phys. **B526**, 136 (1998)
- [9] G. Dvali and M. Shifman, “Dynamical compactification as a mechanism of spontaneous supersymmetry breaking,” Nucl. Phys. **B504**, 127 (1997).
- [10] N. Arkani-Hamed, S. Dimopoulos and G. Dvali, “The hierarchy problem and new dimensions at a millimeter,” Phys. Lett. **B429**, 263 (1998); I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos and G. Dvali, “New dimensions at a millimeter to a Fermi and superstrings at a TeV,” Phys. Lett. **B436**, 257 (1998).
- [11] H. Verlinde, Holography and Compactification, e-Print Archive: hep-th/9906182.
- [12] A. Sen, “Non-BPS states and branes in string theory,” hep-th/9904207.
- [13] L. Girardello, M. Petrini, M. Porrati, A. Zaffaroni, Novel Local CFT and Exact Results on Perturbations of N=4 Super Yang Mills from ADS Dynamics, JHEP 9812 (1998) 022.
- [14] D.Z. Freedman, S.S. Gubser, K. Pilch, N.P. Warner, Renormalization Group Flows from Holography: Supersymmetry and a C-Theorem, e-Print Archive: hep-th/9904017.
- [15] H. Verlinde, “Supersymmetry at large distance scales”, hep-th/0004003.
- [16] S. Kachru, M. Schulz and E. Silverstein, “Self-tuning flat domain walls in 5d gravity and string theory,” hep-th/0001206; N. Arkani-Hamed, S. Dimopoulos, N. Kaloper and R. Sundrum, “A small cosmological constant from a large extra dimension,” Phys. Lett. **B480**, 193 (2000) [hep-th/0001197].

- [17] S. Ferrara, L. Girardello and F. Palumbo, “A General Mass Formula In Broken Supersymmetry,” *Phys. Rev.* **D20**, 403 (1979).
- [18] J. C. Long, H. W. Chan and J. C. Price, “Experimental status of gravitational-strength forces in the sub-centimeter regime,” *Nucl. Phys.* **B539**, 23 (1999)
- [19] P. Horava and E. Witten, “Heterotic and type I string dynamics from eleven dimensions,” *Nucl. Phys.* **B460**, 506 (1996) [hep-th/9510209].
- [20] Lisa Randall, Raman Sundrum, A Large Mass Hierarchy from a Small Extra Dimension, *Phys.Rev.Lett.* 83: 3370-3373, 1999; An Alternative to Compactification, e-Print Archive: hep-th/9906064.
- [21] G. Dvali, G. Gabadadze and M. Porrati, “Metastable gravitons and infinite volume extra dimensions,” hep-th/0002190.
- [22] I. Antoniadis, E. Dudas and A. Sagnotti, “Brane supersymmetry breaking,” *Phys. Lett.* **B464**, 38 (1999).